DEVELOPMENT OF AN ^{14}O ION BEAM AT THE 88" CYCLOTRON

D. Wutte, J. Burke, B. Fujikawa, P. Vetter, S.J. Freedman, R.A. Gough, C. M. Lyneis, Z. Q. Xie,
LBNL, Berkeley, CA

Abstract

At the 88" Cyclotron at the Lawrence Berkeley National Laboratory we are developing an intense ($3 \cdot 10^7$ pps), low energy ^{14}O ion beam to measure the shape of the beta-decay spectrum. The ^{14}O half-life of 71 seconds requires on-line production of the isotope. ^{14}O is produced in the form of CO in a high temperature carbon target using a 20 MeV $^3He^+$ beam from the LBNL 88" Cyclotron via the reaction $^{12}C(^3He,n)^{14}O$. In order to minimize the background radiation for the planned experiment, the ^{14}O atoms must be separated from the other radioactive isotopes produced in the carbon target and implanted into a thin carbon foil.

For this purpose, we have developed an experimental set-up including the target, a transfer line, an ion source, and a low energy ion beam transport line. The major components of this set-up are described. The release and transport efficiency for the CO molecules from the target through the transfer line was measured for various target temperatures. Experimental results of ionization efficiencies for carbon and oxygen using a multicusp and an ECR ion source are presented

1 INTRODUCTION

At the Lawrence Berkeley National Laboratory we have commissioned an ion source test stand for radioactive ion beam development [1] (see figure 1). The primary goal of this test stand is the on-line production of a $^{14}O^+$ ion beam to measure the shape of the ^{14}O beta-decay. The ^{14}O half-life of 70 seconds requires producing the isotope on-line at the 88" Cyclotron. ^{14}O is generated in the form of CO in a high temperature carbon target using a 20 MeV $^3He^+$ beam from the LBNL 88" Cyclotron via the reaction $^{12}C(^3He,n)^{14}O$.

The ^{14}O atoms must be then separated from the other radioactive isotopes produced in the carbon target and implanted into a thin carbon foil in order to:

- minimize the radiation background
- maximize the signal in the beta spectrometer by concentrating the ^{14}O sample size.

For this purpose, an 8 m stainless steel transfer line connects the target chamber to an ECR ion source through a turbo molecular pumping stage. Thus, the turbo pump separates the target vacuum chamber from the ion source. The gas coming from the turbo pump is fed into the ion source and ionized, extracted at energies of 20 to 30 keV and mass separated. To achieve a small sample size for the beta spectrometer, it is planned to implant the $^{14}O^+$ ions in a 2 mm spot on a thin carbon foil. This sample will then be transferred to the beta-spectrometer. The three major experimental requirements for the ion source are:

1. To achieve the necessary ^{14}O particle current of $1\text{-}2 \cdot 10^7$ pps at the implant target, the ion source should be able to provide 10 % ionization efficiency for $^{14}O^+$.
2. At the estimated implantation rate of $1\text{-}2 \cdot 10^7$ pps the expected continuous run of the experiment will be at least 150 hours. Therefore, the ion source should continuously operate for at least 200 hours.
3. The gas hold up time in the ion source must be less than one ^{14}O half-life.

In order to fulfill these demands, a RF multicusp ion source [2] and the AECR-U [3] were tested off-line with respect to ionization efficiency and gas hold-up times. The presented efficiencies Table 1 and 2 quote the overall system efficiencies (ion source and transport line).

Because the experimental requirements could not be met with the cusp source and because of the promising results measured on the AECR-U, the cusp ion source has been replaced by the compact IRIS ECR ion source.

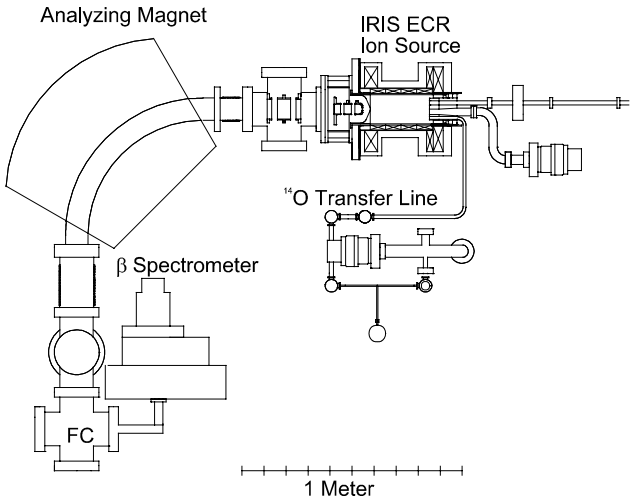

Figure 1: Schematic of the new exotic ion beam test stand and the ^{14}O experiment.

This work was supported by the Director, Office of Energy Research, Office of High Energy Physics and Nuclear Physics Division of the U.S. Department of Energy under contract No. DE-AC03-76SFF00098.

2 EXPERIMENTAL SETUP

2.1 Hot Carbon Target

An all carbon target was constructed using a high porosity carbon material[1]. The target is resistively heated and bolted to water-cooled copper electrodes. Graphite and boron nitride heat shields were then added concentrically around the target.

At 1720 °C and 2 μA cyclotron beam current on the target $3 \cdot 10^7$pps of ^{14}O have been measured at the exit of the turbo pump (at the entrance to the ion source). Figure 2 shows the production rate as a function of target temperature. Therefore at 20 μA primary beam current a production rate of $3 \cdot 10^8$pps of ^{14}O can be expected.
Using the assumed thick target production rate of $2 \cdot 10^8$pps/μA, an efficiency of 7.5 % for this target set-up has been achieved.

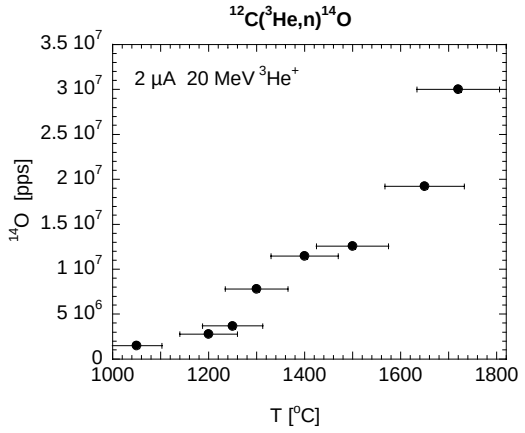

Figure 2: Production rate as a function of target temperature as measured at the end of the transport line.

2.2 Beam-line Layout

The ion beam transport line has been designed around an existing double focusing 90°-sector magnet from the former HILAC injector line at LBNL. It has a bending radius of 54 cm, edge angles of 30 degrees, and a gap width of 3.8 cm. The horizontal waist is located about 43 cm downstream from the vertical waist. Therefore, the ion beam has an elliptical shape after the sector magnet. An additional focusing element will be needed to achieve the required beam spot size of 2mm diameter at the implant foil. The 30 kV extraction system and the following electrostatic transport line consist of an accel-decel extraction system and two sets of einzel lenses. It was optimized with the ion trajectory code IGUN [4]. The use of two einzel lenses allows limited independent control over both beam size and divergence at the magnet entrance. Therefore, the ion optics can be adjusted over a wide range of extraction voltages and current densities (3 mA/cm^2 to 60 mA/cm^2, corresponding to a total extracted current of 100 eμA to 2 emA), as verified experimentally. The extraction system and the two einzel lenses are mounted on a single flange to ensure a proper alignment.

3 OFF-LINE ION SOURCE TESTS

3.1 Multicusp Ion Source

A detailed description of the RF driven multicusp ion source used in this study, together with its basic characteristics can be found elsewhere [2]. The main concerns with this type of ion source with respect to the production of radioactive ion beams are the relative high operation pressure as well as the reliability of the ion source.
Ionization efficiencies were measured off-line for singly charged argon, oxygen, carbon, and carbon monoxide ions using calibrated leaks. The maximum ionization efficiencies for all measured species are summarized in Table 1. The experimental gas hold up time is described by the exponential fit $A \cdot \exp(-t/\tau_{fast}) + B \cdot \exp(-t/\tau_{slow})$. The fast component describes the holdup time of the ions in the plasma, the slow component is related to the wall sticking time. The signal drops to about 70 % within the time τ_{fast}.

Table 1: Ionization efficiencies and hold up times for singly charged oxygen and carbon produced by RF driven cusp ion source.

ion	calibrated leaks					
	CO %	τ_{fast} (sec)	**O_2** %	τ_{fast} (sec)	**Ar** %	τ_{fast} (sec
O^+	0.7	42	0.7	36		
C^+	0.33	13				
CO^+	1	17				
Ar^+					26.3	6

Whereas a promising ionization efficiency of up to 26.3% and a gas hold-up time of 6 seconds have been measured for argon, the ionization efficiencies for CO^+ and O^+ are much lower. With the cusp source the best efficiencies achieved have been 1 % for CO^+, 0.7 % for O^+ and 0.33 % for C^+. In general rather long ion hold-up times have been observed, the longest has been measured for O^+.

The discrepancy between the argon efficiencies and the carbon or oxygen efficiencies may be explained by the differences in the plasma wall sticking probabilities. Noble gases can be recycled into the plasma, explaining the high efficiency for argon. On the contrary, carbon and oxygen tend to stick at the plasma chamber wall, leading to low source efficiencies in the cusp ion source.
The average ion source lifetime for the above mentioned performance tests was about 15 hours, limited by the failure of the porcelain-coated copper antenna.

3.2 AECR-U Ion Source

A detailed description of the AECR-U ion source (Advanced Electron Cyclotron Resonance-upgrade) can be found elsewhere [3]. The source is optimized for production of high charge state ions. Ionization efficiencies and gas hold-up times for high charge state ions have been measured with the LBNL AECR-U ion source for various gases [5].
Listed in Table 2 are the ionization efficiencies and decay times of various high charge state ion beams from CO, CO_2 and O_2. These gases may react with or stick to the plasma chamber surface made of aluminum. Nevertheless efficiencies of up to 25% were achieved for C^{4+}, 33% for O^{6+} and more than 10% for C^{5+} and O^{5+}. The shortest gas hold up time has been measured for ions produced from CO, which behaves as a noble gas prior to dissociation.

Table 2: Ionization efficiencies and hold up times for selected charge states of oxygen and carbon produced by the LBNL AECR-U ion source.

	calibrated leaks					
ion	**CO** %	τ_{fast} (sec)	**CO_2** %	τ_{fast} (sec)	**O_2** %	τ_{fast} (sec)
O^{3+}					3.9	
O^{4+}					8	
O^{5+}	11.5	3.2	12.5		11.3	4.7
O^{6+}	26.3	3.2	33	7.1	16.0	
O^{7+}	7.5	3.2	7.44		5.6	
C^{4+}	23.7	2.9	23.4	5.6		
C^{5+}		2.9	15.4			

4 IRIS ECR ION SOURCE

A compact ECR ion source IRIS (Ion source for Radioactive ISotopes) shown in Figure 3, has been installed on the radioactive ion beam test stand, replacing the multicusp ion source. An existing 2.45 GHz ECR ion source [6] was upgraded for 6.4 GHz microwave operation. The mirror field was improved to reach a maximum field of 0.7 Tesla at the injection and 0.4 Tesla at the extraction. At the plasma chamber-wall the sextupole-field strength reaches 0.32 Tesla.
The ion source consists of one plasma stage only. The microwaves are launched through an off-axis wave-guide terminated at a bias plate in the injection region. The aluminum plasma chamber has a diameter of 13.5 cm and the mirror length is 28.3 cm, providing a relatively large plasma volume of 5 liters. The plasma chamber is double-walled to accommodate cooling water.
IRIS is expected to start operation in the beginning of April.

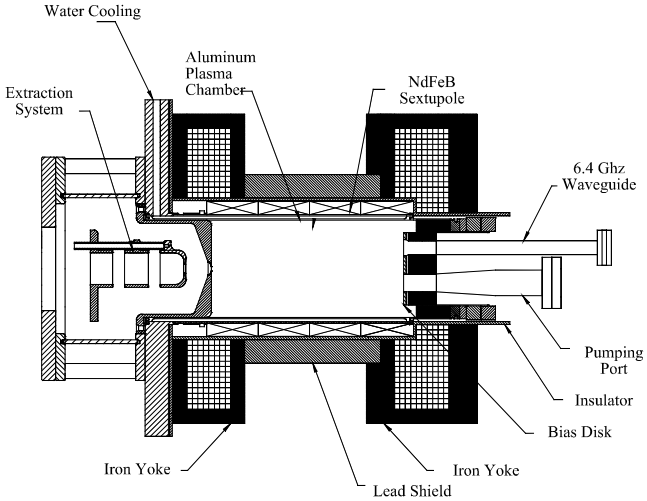

Figure 3: An elevation view of the IRIS ECR ion source.

5 REFERENCES

[1] D. Wutte, J. Burke, B. Fujikawa, P. Vetter, S.J. Freedman, R.A. Gough, C. M. Lyneis, Z. Q. Xie, Development of a radioactive ion beam test stand at LBNL, Proceedings of the Heavy Ion Accelerator Technology Conference (HIAT'98), Argonne National Laboratory, Illinois, USA, 5-10 October 1998
[2] Wutte D.C., S. Freedman, R.A. Gough, Y. Lee, M. Leitner, K. N. Leung, C.M. Lyneis, D.S. Pickard, M. D. Williams, Z. Q. Xie, NIMB **42** (1998)
[3] Z. Q. Xie and C. M. Lyneis, Proceedings of the 13th International Workshop on ECR Ion Sources, Texas A&M, College Station, USA, 16 (1997).
[4] R. Becker, W. B. Hermannsfeldt, RSI **63**, 2756 (1991)
[5] Z. Q. Xie, D. Wutte, C. M. Lyneis, to be published
[6] D. C. Wutte, M. A. Leitner, M. D. Williams, K. N. Leung, R. A. Gough, RSI **69**, 712 (1998)